Calculating leakage from the Rio Grande to the shallow ground-water system for the Middle Rio Grande Cochiti Dam to Bernardo

Computation of daily leakage to or from the river and the shallow ground-water system was made. These calculations are based on gradients using water-surface elevations of the Rio Grande and riverside drain(s). Flow of water from the river was calculated using the equation Q=KIA where Q= flow in cubic feet per day, K is the hydraulic conductivity in feet per day , I is the average gradient from the river to the drain(s), and A is the area through which water will flow to or from the river, in square feet.

River elevations were derived using the U.S. Bureau of Reclamation (USBR) aggredation-degredation data and maps (USBR, 1992). A range line was selected by the USBR for about each 500 feet of river length from Cochiti Dam to range line 1794, at the headwaters of Elephant Butte reservoir. For each of these range lines, land and water surface elevations were estimated using orthophotgraphic maps through work done by a USBR contractor. In estimating river elevations in the river leakage study a range line was selected at about each river mile starting at Cochiti Dam and ending at Bernardo. The selected range lines formed the upper and lower ends of a cell that contained the river and adjacent riverside drains, if there was riverside drain. River bottom elevations were estimated by subtracting the estimated depth of flow at each of the selected range lines from the water surface elevation. The depths of flow were estimated using U.S. Geological Survey (USGS) flow measurement data that corresponded to a flow that was in the river on February 21, 1992 from Cochiti Dam to near the Alameda Boulevard bridge in Albuquerque and on February 24, 1992 from near the Alameda bridge to Bernardo. Average measured depth of flow was taken from flow measurement data at gages Rio Grande below Cochiti Dam (08317400), Rio Grande near Alameda (08329928), Rio Grande at Albuquerque (08330000), and Rio Grande at Rio Bravo Bridge (08330150), and Rio Grand Floodway near Bernardo (08332010). Depth of flow for each cell between the gages was estimated by dividing the difference in depth of flow of 2 adjacent gages by the number of cells. This value was then added to the depth of the upstream gage.

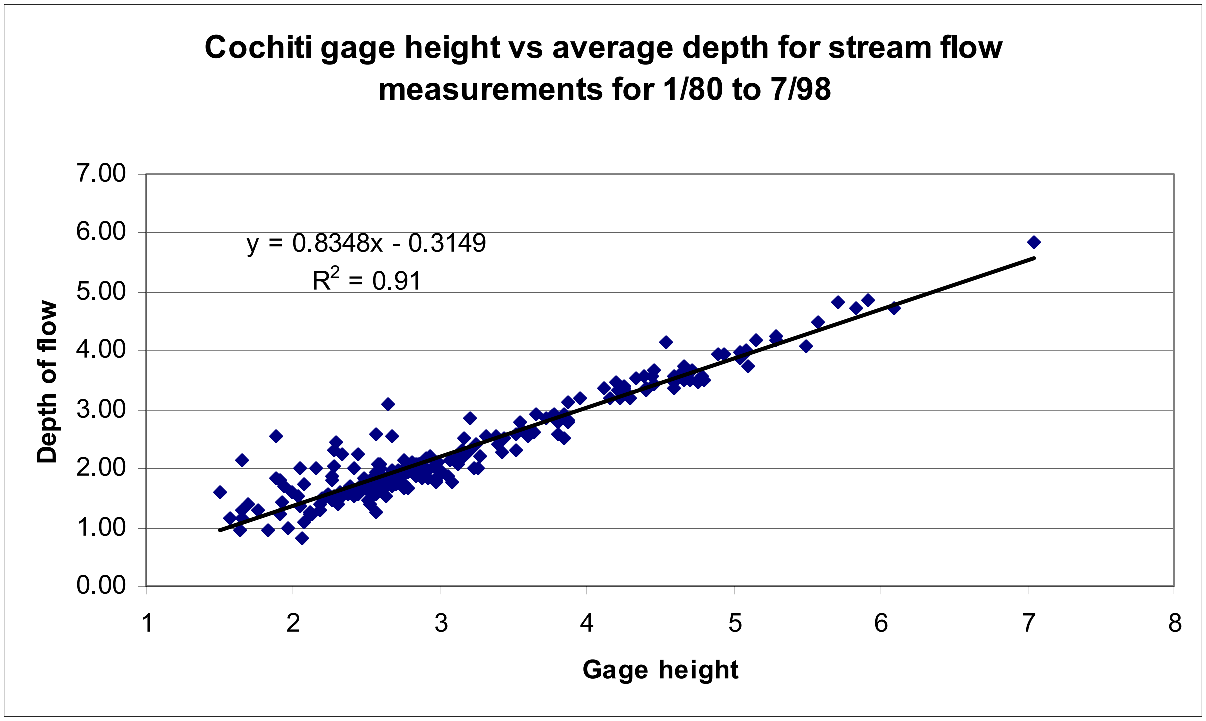
Riverside drain bottom elevations were taken from digital data obtained from original drain engineering plans. Digital data were created by the USGS through a cooperative project with the City of Albuquerque, Office of the New Mexico State Engineer, and the Middle Rio Grande Conservancy District. Riverside drain traces were digitized and divided into many arcs with top and bottom nodes at each arc. Drain bottom elevation and drain slope that corresponded to the upstream most node of each arc were part of the digital data set. A digital trace of the river, riverside drains, and cells corresponding to selected range lines were overlain using ARC/INFO. Drain bottom elevation data at the same location of the river bottom data were not available. Riverside drain bottom elevation data were estimated at each range line using the slope of the drain and the distance from a node on a riverside drain arc to the next range line.

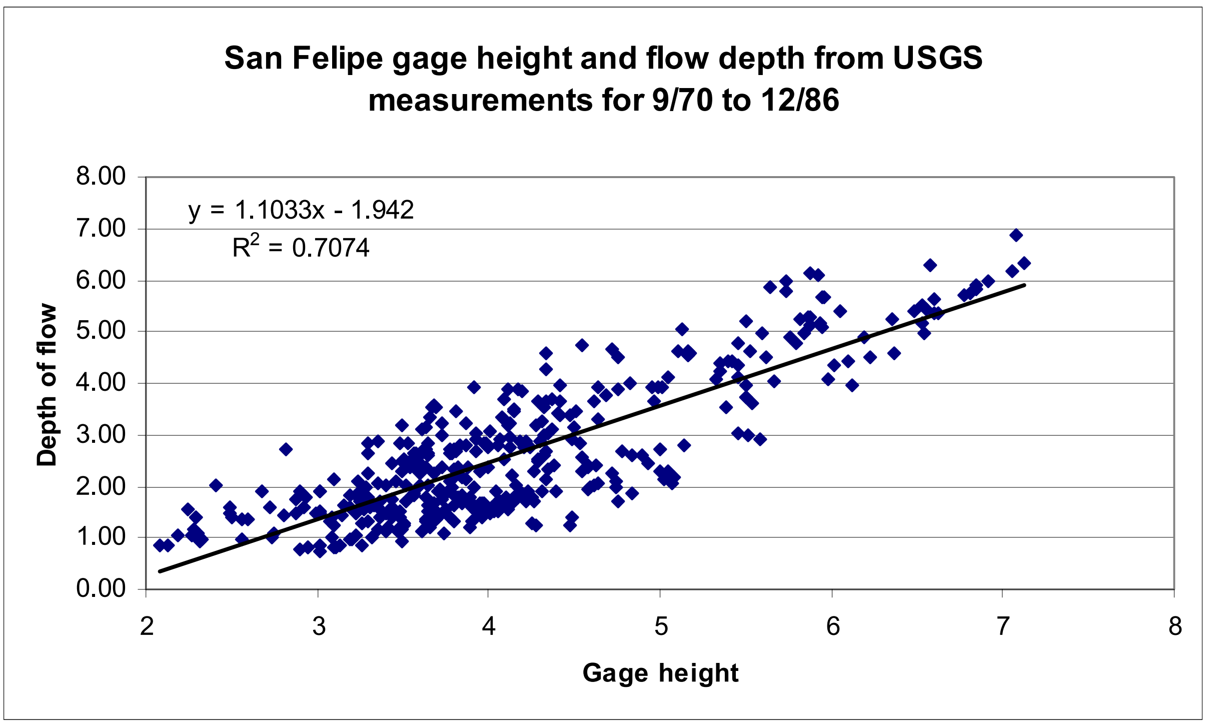
River water-surface elevations for each cell were estimated using the gradient from the upstream to a downstream gage used to define a river reach. This gradient was multiplied by the distance from the upstream gage to the top of the second cell then the distance from the second cell to next cell etc. The product of the above operation was subtracted from the water surface elevation at the upstream gage or cell to estimate the water surface elevation for the next downstream cell. A river water surface elevation for each cell was estimated using this procedure for each day. A riverside drain water surface elevation was estimated for each cell by averaging the drain bottom elevation at the top and bottom of each cell and adding the average monthly drain depth of flow shown in table below.

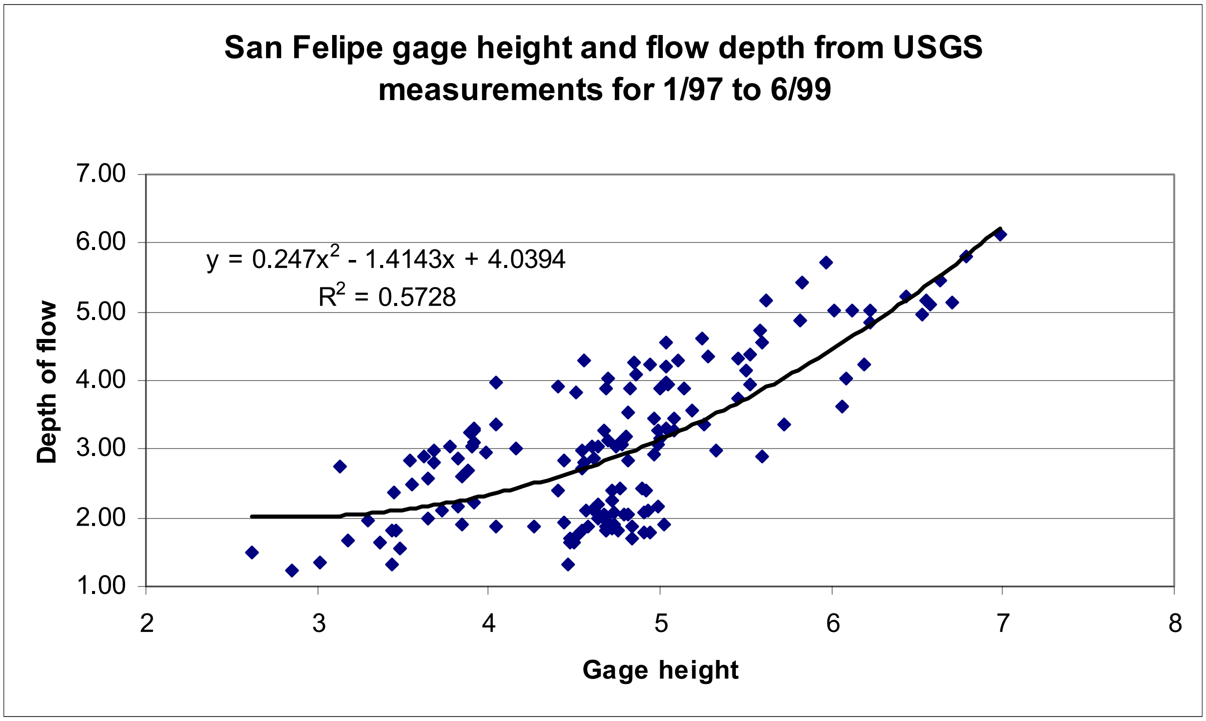
Month	Corrales ave depth	Bernardo ave depth	Atrisco Ave depth	Albuquerque Ave depth	Average depth
1	1.181769	0.99204			1.1
2	1.65619	1.001834	1.182857	1.128848	1.2
3	1.421467	1.310291	1.294467	2.20885	1.6
4	1.973333	1.495253	1.242857	2.192405	1.7
5	1.910627	1.69312	2.426587	2.175676	2
6	1.972592	1.618449	1.572067	2.572063	1.9
7	1.788063	1.692995	1.361111	2.55	1.8
8	1.945357	1.770662	1.133397	2.430597	1.8
9	1.823144	2.187433	1.184127	2.59887	1.9
10	2.085522	2.196936	1.347297	2.433738	2
11	1.285774	1.04386	1.232996	1.544767	1.3
12	1.247312	1.046976	1.200342	1.281906	1.2

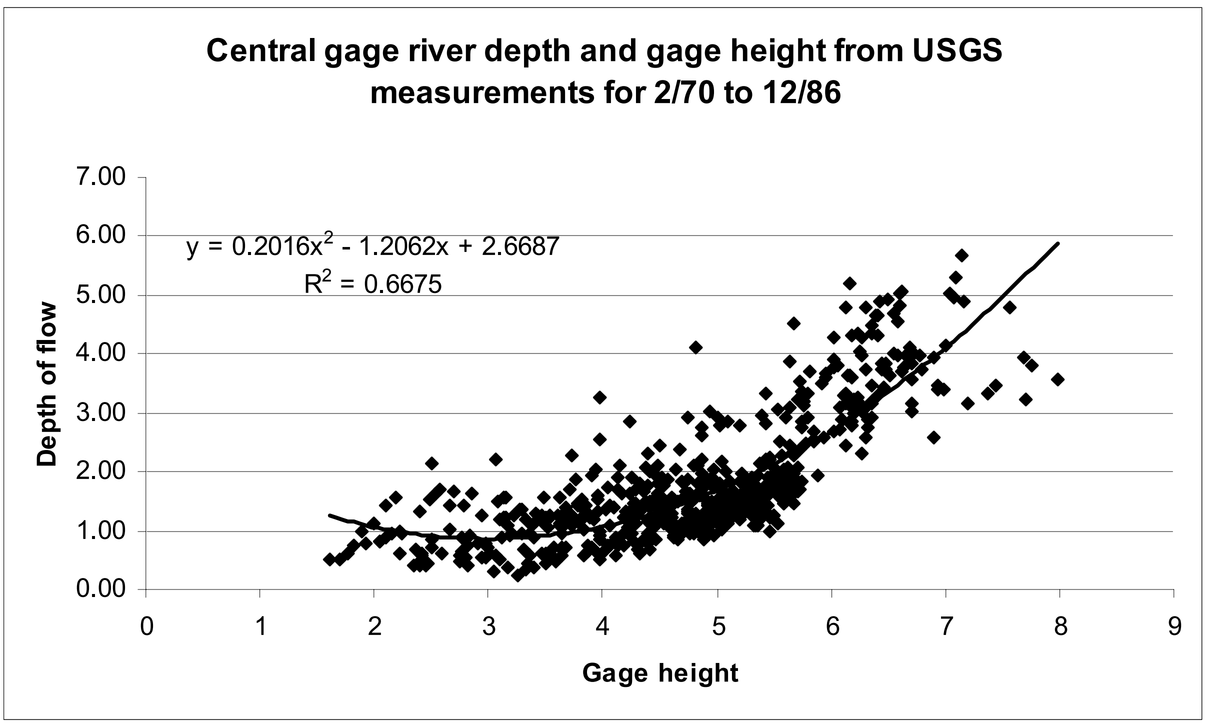
The gradient from the river to the drain(s) was estimated using the estimated river water-surface elevation in each cell, the distance from the river to the drain(s), and the estimated water-surface elevation in the drain(s). This gradient is assumed to be the driving force for leakage to or from the river. Positive gradients generate flow from the river. The cells were used to define discrete parts of the floodplain. Within each cell the parameters of the flow equation were defined and the flow to or from the river computed.

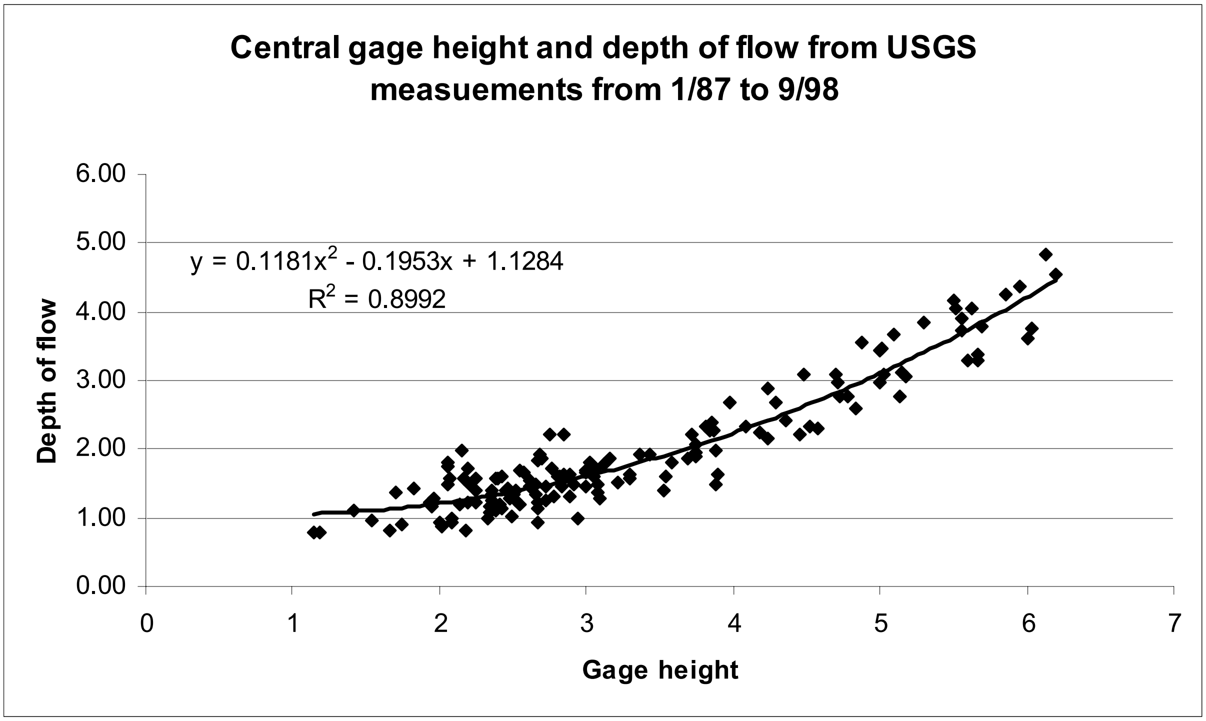
A FORTRAN program was developed to compute river leakage. The program calculates a water surface elevation for the river and for each riverside drain in each cell for each day. The average gradient from the river to the east and to the west drains are computed separately. Input to the program are gage heights for Rio Grande below Cochiti Dam (08317400), Rio Grande at Albuquerque (08330000), and Rio Grande Floodway near Bernardo (08332010) and horizontal and vertical hydraulic conductivity for each reach. The average distance from the east side of the river to the riverside drain east of the river, using distances at each of the range lines that form the upper and lower boundaries of the cell are used. Distances from the river to the east side riverside drain were measured from orthophotoquad maps at a scale of 1 inch is equal to 400 feet on the ground (USBR, 1992). The average distance from the west side of the river to the riverside drain west of the river, using distances at each of the range lines that form the upper and lower boundaries of the cell are also used. The surface area of the river was obtained using ARC/INFO by intersecting the bounding traces of the river edges with the cells. The surface area of the river was assumed to be equal to the bottom area and this value was used to compute vertical leakage from the river. The distance from the river to the riverside drains and the river surface area were adjusted using relationships between river stage and the change in river area derived from USGS flow measurement data. If the river surface area decreased then the distance from the river to the drains increased. The area through which horizontal flowing river leakage had to pass was the length of each side of the river in each cell times the estimated depth of flow of the river in that cell times 2. The depth of flow was multiplied by 2 assuming that flow lines from river to the shallow ground-water system would not be straight lines from the river bank to the ground water system but that there would be some curvature at the river bank and bottom that would create an effective area of flow from the river greater than the depth of river flow. River depth is varied according to the relationships established between gage height and flow depth for each gage in the middle valley. Depth of flow was changed daily based on the gage height-flow depth relationships presented below. In order to assure consistency in the daily depth of flow between gages and reaches the difference in depth of flow at an upstream and a downstream gage in a reach was divided by the number of cells in that reach and the depth for each cell incremented by that value. Vertical flow from the river used average gradients and vertical hydraulic conductivities from Bartalino and Niswonger (1999).

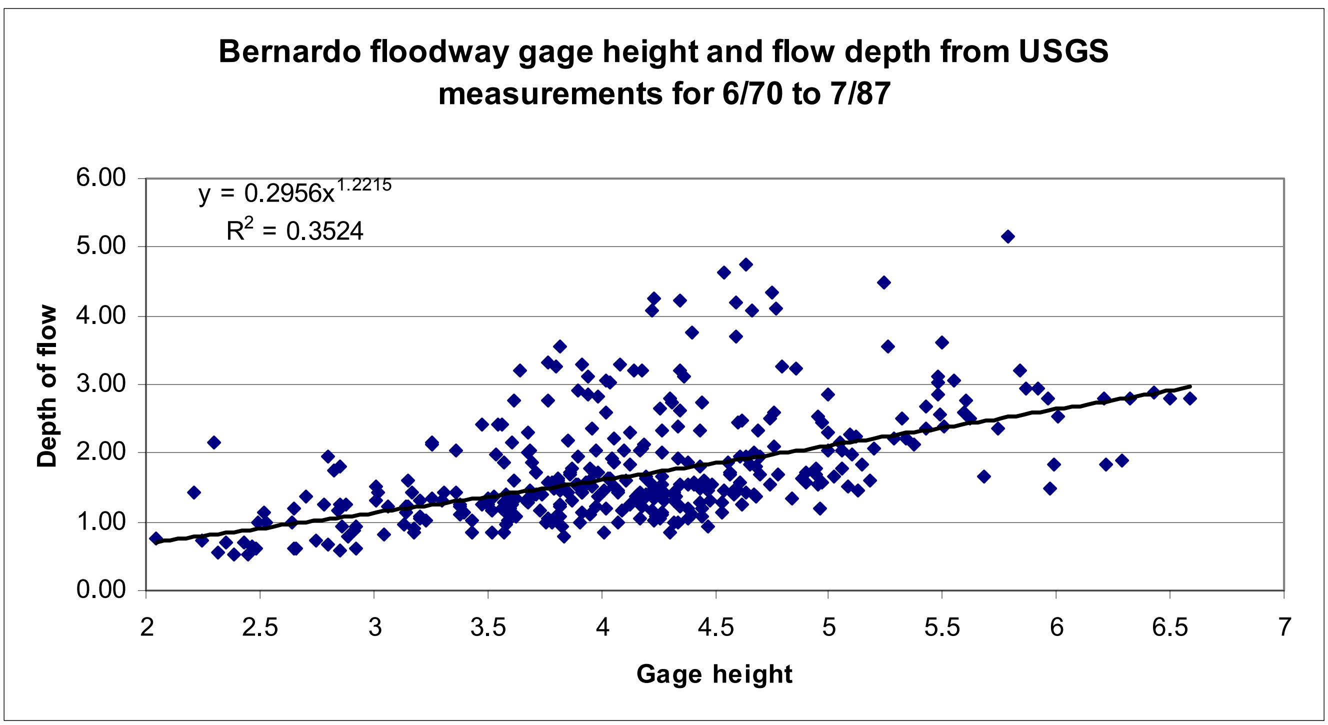

Cochiti gage height vs average depth for stream flow measurements for 1/80 to 7/98
y = 0.8348x - 0.3149
R2 = 0.91
Depth of flow
Gage height
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1
2
3
4
5
6
7
8

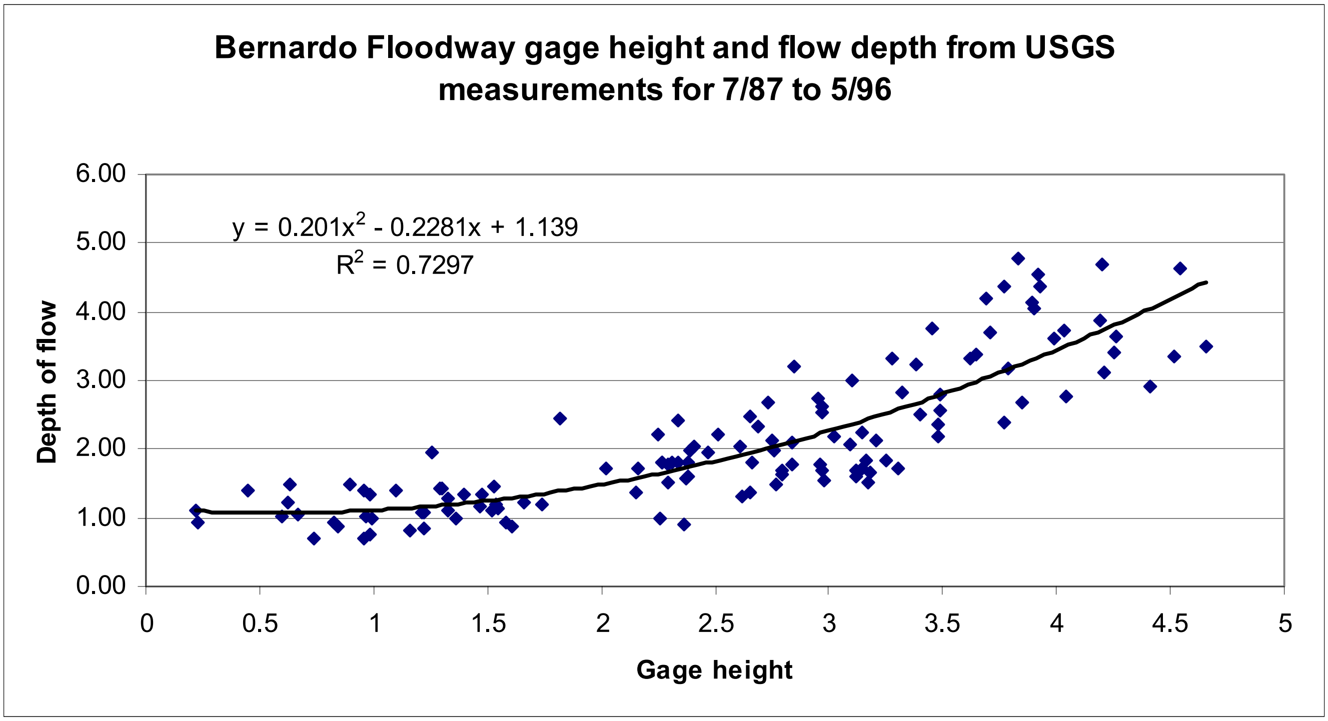

San Felipe gage height and flow depth from USGS measurements for 9/70 to 12/86
y = 1.1033x - 1.942
R2 = 0.7074
Depth of flow
Gage height
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2
3
4
5
6
7
8

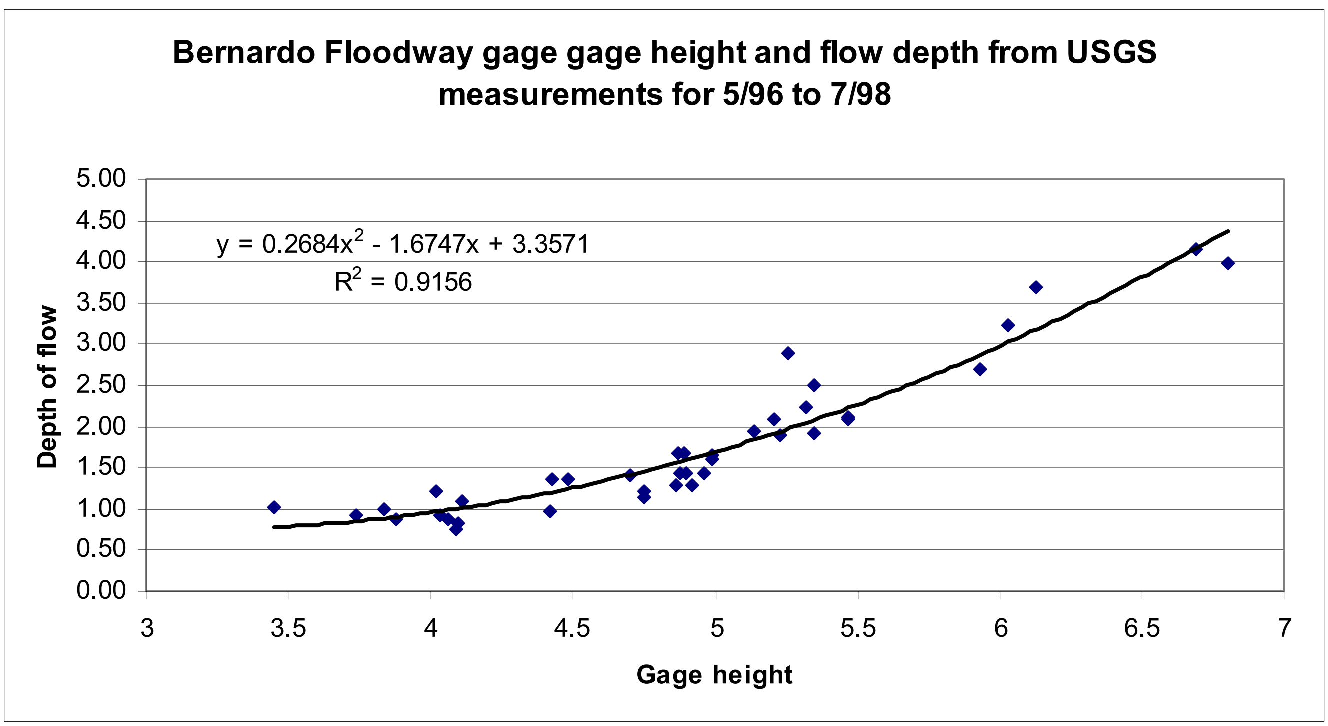

San Felipe gage height and flow depth from USGS measurements for 1/97 to 6/99
y = 0.247x^2 - 1.4143x + 4.0394
R^2 = 0.5728
Depth of flow
Gage height
7.00
6.00
5.00
4.00
3.00
2.00
1.00
2
3
4
5
6
7
8


Central gage river depth and gage height from USGS measurements for 2/70 to 12/86
y = 0.2016x^2 - 1.2062x + 2.6687
R^2 = 0.6675
Depth of flow
Gage height
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
1
2
3
4
5
6
7
8
9


Central gage height and depth of flow from USGS measuements from 1/87 to 9/98
y = 0.1181x2 - 0.1953x + 1.1284
R2 = 0.8992
Depth of flow
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
1
2
3
4
5
6
7
Gage height


Bernardo floodway gage height and flow depth from USGS measurements for 6/70 to 7/87
y = 0.2956x1.2215
R2 = 0.3524
Depth of flow
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
Gage height

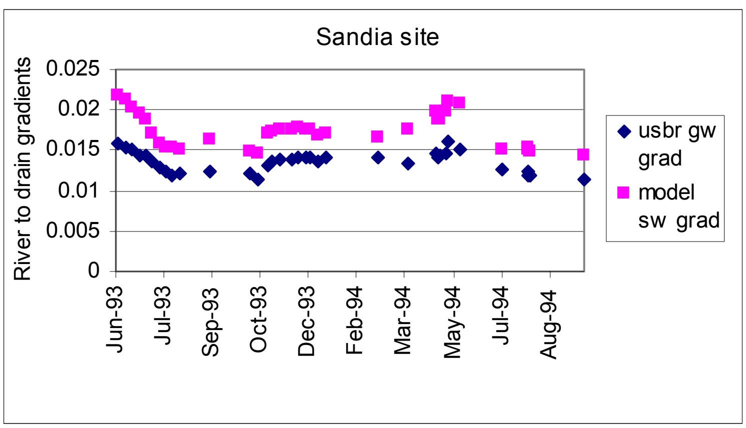

Bernardo Floodway gage height and flow depth from USGS measurements for 7/87 to 5/96
y = 0.201x2 - 0.2281x + 1.139
R2 = 0.7297
Depth of flow
Gage height
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

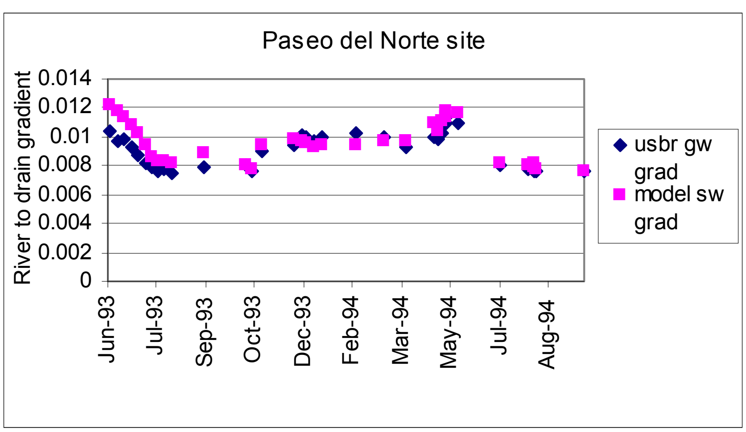

Bernardo Floodway gage gage height and flow depth from USGS measurements for 5/96 to 7/98
y = 0.2684x2 - 1.6747x + 3.3571
R2 = 0.9156
Depth of flow
Gage height
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
3
3.5
4
4.5
5
5.5
6
6.5
7

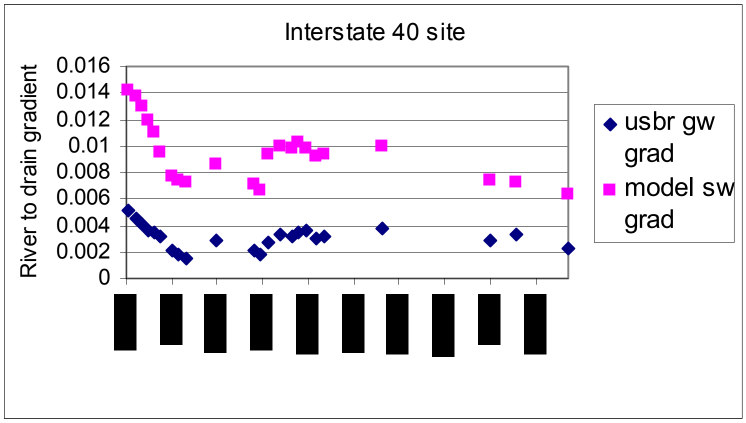
The FORTRAN program was calibrated using river to drain gradient and leakage data from Hansen (no date). This investigation established temporary surface-water elevation gages at the river, the east riverside drain at some sites, and selected canals. Shallow piezometers at 4 sites in the Middle Valley were also installed. Site 1 was near the confluence of the North Diversion channel and the Rio Grande, the Sandia Site; site 2 at the Paseo del Norte bridge crossing, the Paseo del Norte site; site 3 near the Interstate 40 bridge, the I40 site; site 4 near the Albuquerque zoo, the Tingley site; and site 5 at the Rio Bravo Boulevard bride, the Rio Bravo site. Cells used in this investigation that corresponded to the 4 sites in the Hansen (no date) investigation were used to compare river to drain gradients and to match river leakage values by varying horizontal hydraulic conductivity in the FORTRAN program until river leakage values were similar to those reported by Hansen (no date).

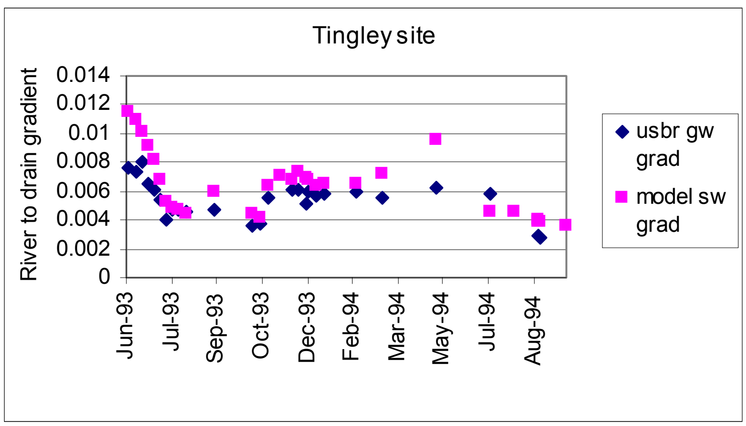
River to drain gradients were not computed by Hansen (no date) but data were available to compute these gradients at the Sandia and Rio Bravo sites. At the Sandia site there were 4 days when river to drain gradients could be computed using the USBR elevation data. Using FORTRAN estimated river to drain gradients for those same 4 days the average FORTRAN gradients are .00728 greater than the average gradients computed using USBR data. For the Rio Bravo site there were 11 days when USBR data were available to compute river to drain gradients. The average FORTRAN computed river to drain gradients for the same 11 days that have USBR data available to compute gradients are .00516 greater than the average USBR river to drain gradients.

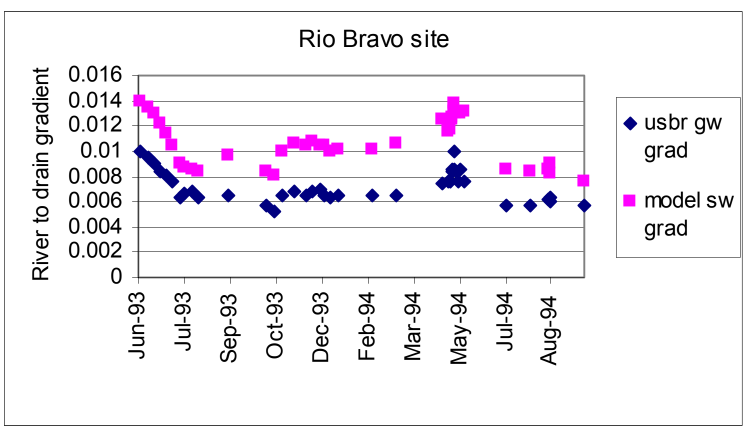
Hansen (no date) reported gradient values from a piezometer near the river to a piezometer on the river side of the east riverside drain at all sites (usbr gw gradi). The gradients computed by the FORTRAN program are from the river to the east riverside drain (mod sw grad) so these two gradient data sets are not exactly comparable. River to drain gradients computed by the FORTRAN program were compared to gradients between a piezometer near the river and a piezometer near the east side drain (Hansen, no date). Shown below are plots comparing USBR well to well gradients and FORTRAN computed river to drain gradients.







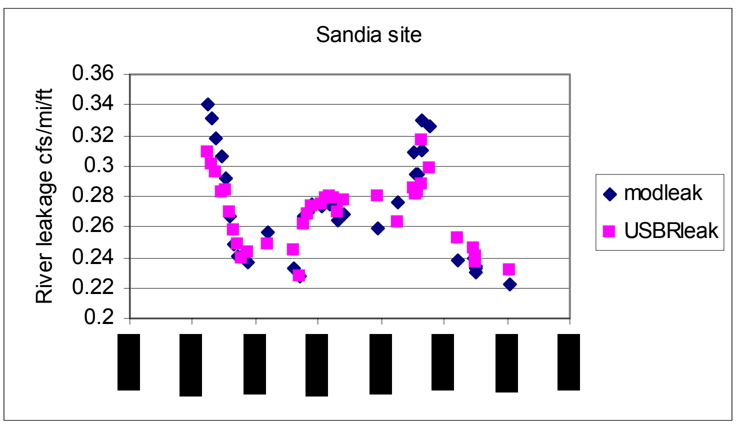


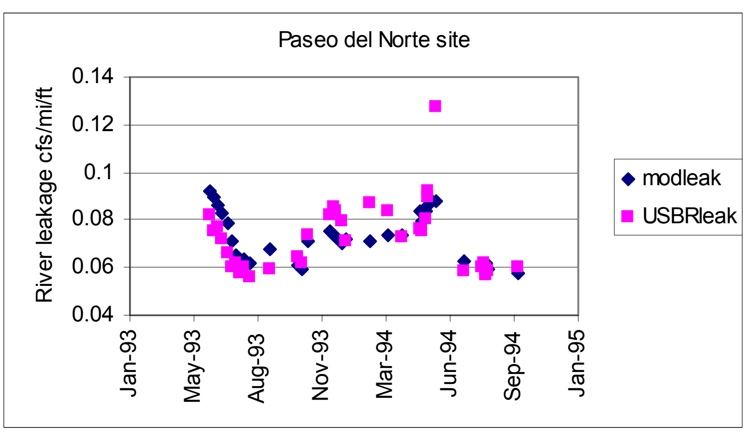


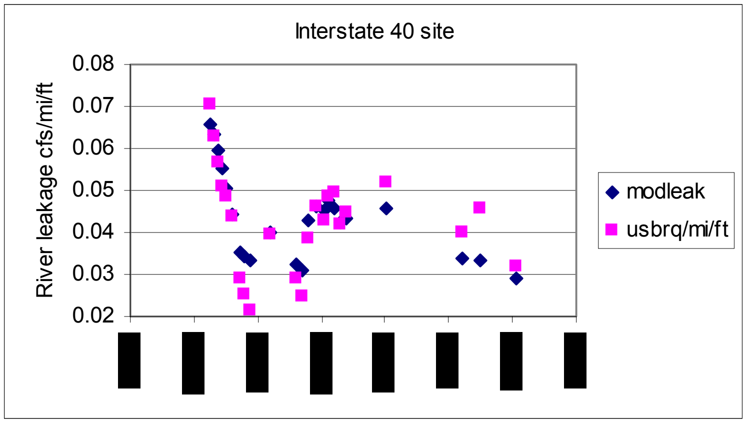
The chart below presents the average USBR hydraulic gradients from a piezometer near the river to a piezometer near the east riverside drain and the average FORTRAN hydraulic gradient from the river to the east riverside drain. In all cases the FORTRAN computed gradient is greater than the USBR gradient. The gradient differences are caused by one or more of the following: the gradients are not based on the same water elevations, the FORTRAN computed gradients use different river to drain distances than the USBR gradients and the FORTRAN river to drain distances are varied each day depending on the gage height of the river, and the FORTRAN gradients are based on average estimated river water surface elevations for a cell that is about 1 mile in length. Considering these differences the FORTRAN river to drain gradients probably represent an appropriate gradient that can be used in estimating river leakage

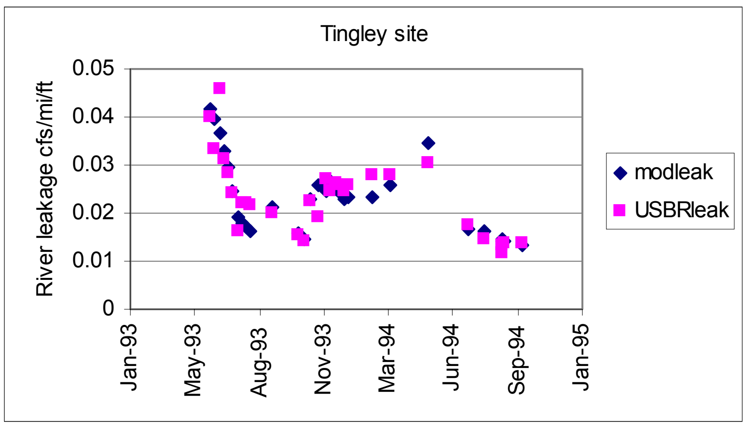
Site	Number of days	USBR average gradient	FORTRAN average gradient	Average gradient difference
Sandia	36	0.01352	0.01739	-0.00509
Pase del Norte	36	0.00899	0.00948	-0.00049
Interstate 40	23	0.00308	0.00943	-0.00635
Tingley	30	0.00541	0.00642	-0.00101
Rio Bravo	41	0.00721	0.01077	-0.00356

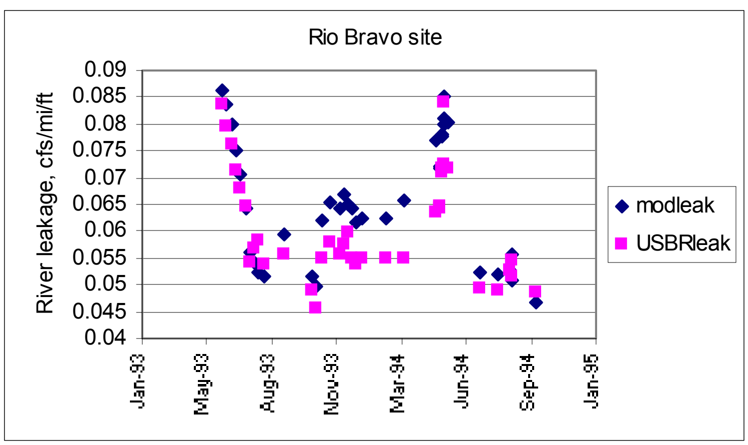
River leakage reported by Hansen (no date) are cubic feet per second (cfs) per mile of river. Depths used by Hansen (no date) to compute leakage from the river ranged from 65 to 80 feet depending on the site. Using the reported depths assumes the river is this deep and is not valid. The reported river leakage values (Hansen (no date) were divided by the depth used in the leakage calculations and river leakage computed in the FORTRAN program were divided by the river depth used in these calculations. These unit leakage values were compared in the calibration procedure. The graphs below show the USBR leakage (USBRleak) and the FORTRAN computed leakage (modleak).











The table presented below provides statistics relative to the match and the horizontal hydraulic conductivity used at each of the site.

Site	Number of days	FORTRAN average leakage (cfs/mi/ft)	USBR average leakage (cfs/mi/ft)	Average flow difference (cfs/mi/ft)	Horizontal hydraulic conductivity (ft/day)
Sandia	36	0.27156	0.26814	-0.00341	250
Pase del Norte	36	0.07197	0.07185	-0.00012	125
Interstate 40	23	0.04348	0.04282	-0.00066	78
Tingley	30	0.02051	0.02098	0.00048	60
Rio Bravo	41	0.06544	0.06144	-0.00401	100

The RiverWare model uses leakage for entire reaches so the horizontal hydraulic conductivity values for the sites were averaged. There were no USBR sites in the Below Cochiti to San Felipe reach to calibrate against so the value used at the Sandia site of 250 ft/day was used. In the San Felipe to Central reach the Sandia, Paseo del Norte, and Interstate 40 sites were used for an average of 150 ft/day. The Tingley and Rio Bravo sites were used in the Central to Bernardo reach with an average hydraulic conductivity of 80 ft/day. Jack Veenhuis reported a gross leakage from the river of about 285 to 295 cfs per day in a reach from about 3 miles below the Highway 44 bridge and the Rio Bravo bridge. Flows were measured in the winters of 1994-95 through 1997-98. During 4 measurement efforts river flow was measured at several places along the reach and all inflows to the reach were measured. An assumption was made that all flows in the drains that returned to the river originated as leakage from the river. Using the gradients and the horizontal hydraulic conductivities reported above the average river leakage computed by the FORTRAN program for this reach was about 110 cfs per day. The discrepancy between flow reported by Veenhuis and that computed by the FORTRAN program might be because not all flow returning to the river originated as river leakage. If there were another source of water for flows returning in the drains then the leakage values reported by Veenhuis would be decreased.

Average gross leakage from each reach, by month, is shown below.